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**The Effect of Noise-Abatement Profiles on Noise Immissions and
Human Annoyance Underneath a Subsequent Climbpath.**

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Introduction.

The most economical climbpath of a departing aircraft satisfies the variationally optimal altitude-airspeed management program defined by the Euler-Lagrange principle, whereby the derivative of the rate of gain of energy of the aircraft with respect to the equivalent total-energy altitude must go to zero (Fig. 1).

In the practical operation of aircraft, an initial climb must be specified to raise the aircraft to an altitude at which terrain clearance and the restraints imposed by air-traffic-control considerations permit the pilot to accelerate the aircraft toward the optimal altitude-airspeed management program.

Noise-abatement climb procedures, in general, lead to adverse deviations of the climb profile from the variationally optimal profile. In fact, whereas climb procedures with deep power cutbacks may minimize the noise immissions in selected areas close to the departure end of the takeoff runway during the early takeoff climb, the further initial en route climb, when full climb power is restored, continues at altitudes (potential energy) and airspeeds (kinetic energy) that are lower than those attainable in a variationally optimal climb. Hence, the noise impact underneath the more distant points underneath the en route climbpath, and the annoyance imposed on and reported by residents there, are increased by the initial noise-abatement climb, in some instances substantially.

The en route noise problem created by initial noise-abatement climbouts with deep power

cutbacks, is aggravated in climbs over rising terrain.

The Range of Distances Wherein Aircraft-Noise Immissions on the Ground can be Affected Substantially by Takeoff Noise-Abatement Climb Profiles.

En route noise immissions on the ground can be affected by the detailed characteristics of intended noise-abatement climb profiles and procedures to an extent of 10 or more nautical miles (n.mi.) from the start of takeoff roll of a large or heavy air-carrier-type airplane.

The present paper constitutes an extension and development of (1) suggestions submitted on May 8, 1982 to noise-abatement officials of the airports at Frankfurt, Federal Republic of Germany (FRG), and Zurich, Switzerland, and the air carriers Lufthansa German Airlines and SWISSAIR, (2) a paper presented in 1985 (Ref. 1), and (3) a paper presented on January 18, 1989 (Ref. 2).

Fundamentals of Noise-Abatement Climb Planning.

The only *a priori* requirement for any and all procedures of flight planning is *flight safety*. All other criteria are, within reason, variable and negotiable.

Several parameters and variables are fundamental to the safety, feasibility, and efficiency of a noise-abatement climb procedure.

(a) **Geometry:** The angle of the climbpath relative to the horizon, the angles and angular

velocities in pitch, yaw, and roll and the profile of the underlying terrain.

(b) **Aerodynamics:** The angle of attack of the airplane, the true airspeed, and the thrust of the powerplant, the airframe configuration, and "decision points" along the climb path and the lift and drag characteristics of the airplane at those points.

(c) **Meteorology:** The horizontal and vertical distribution of temperatures and wind velocities within the airspace around the airport.

Flight Safety and Energy Efficiency - Fundamental Requirements for a Climb.

In an initial climb of an aircraft, flight safety requires that (1) the climb path of the aircraft continue to rise if the critical engine becomes inoperative, and (2) the aircraft can maintain straight flight against the yawing moment produced by the surviving engine(s).

Optimal Climb of an Aircraft.

The best energy utilization in climb consists in the attainment of the total energy ultimately required in cruise, that is, the sum of (i) the potential (altitude) energy and (ii) the kinetic energy (the square of the velocity), be attained in the shortest time or in the shortest distance or with the least consumption of fuel, Fig 1 (Ref. 3)

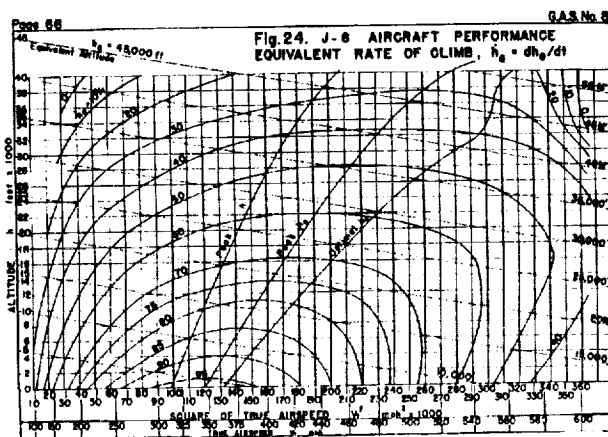


Fig. 1. Schematic Description of the Optimal Climb of a High-Performance Airplane.
Peak - Geometrically optimal. Optimal - energetically optimal

Considerations of noise abatement and air-traffic control impose an initial compromise which affects not only the economy of the subsequent climb, but indirectly, the en route noise immissions underneath that climb path.

The Minimal Deck Angle for Safe Flight.

Airworthiness regulations require that, with a powerplant inoperative, the aircraft must maintain straight flight at a specified climb angle. Many experienced pilots will maintain a climbing airspeed and deck angle at which the requirement could be met without any increase in thrust by the surviving engine.

This issue was discussed at a dedicated FAA Conference with especial reference to an initial climb with sharp thrust cutback shortly after takeoff (Ref. 4).

Optimal Climb Versus Steepest Climb.

The optimal climb requires higher airspeeds for the simultaneous attainment of a prescribed altitude (potential energy) and a prescribed cruising airspeed (kinetic energy) than a climb to the specified altitude alone.

Pursuant to the Euler-Lagrange principle of variational calculus, the optimal airspeed-altitude program runs along a curve which, in a h/Vt^2 diagram, connects the points at which the derivative of the function dh_e/dt (that is, the rate of gain of the equivalent or total energy translated into altitude) with respect to the equivalent altitude h_e , goes to zero (Fig. 1).

The Initial Climb.

In general, aircraft lift off the ground with lift-augmenting devices extended. Although the aircraft is then enabled to climb initially at a steeper angle and to attain a given altitude in less time and over a shorter distance, such procedure delays the acceleration of the aircraft toward its optimal climb program.

It follows that any deviation from the optimal airspeed-altitude program must of necessity

cause the aircraft to attain a lower altitude and/or a lower airspeed at any point of the subsequent climb. Any non-optimal initial climb must increase the noise immissions underneath the subsequent en route climb path.

An initial unaccelerated climb with high-lift devices deployed delays the attainment of zero-flap maneuvering airspeed at which a 30-degree angle of bank, required for en route noise-abatement trajectories is practicable.

Factors That Govern Noise Immissions on the Ground.

1. For middle and high sound frequencies, a doubling of the distance reduces the sound-pressure immission levels by approximately 6 dB, subject to variations in air temperature and moisture content.
2. A reduction of the engine pressure ratio (EPR) is regarded as more effective for noise abatement than a greater gain in altitude at a higher EPR.
3. The deck angle and azimuth of the climbing aircraft affect the directional noise immission on the ground.
4. Greater airspeeds diminish the shear between the propulsive jets and the atmosphere and, hence, the sound emission therefrom.
5. Faster flight reduces the "time of sweep" of noise immissions and single-event noise-exposure levels on the ground.
6. A sharp turn during initial climb may expose points on the ground within that turn to a longer exposure time and, hence, a greater single-event noise-exposure level (Ref. 5).

Available Levels of Engine Thrust.

Aircraft with low-bypass-ratio engines (1.1 to 1.5) are normally flown with (1) *takeoff thrust* (maximum or reduced); (2) *maximum climb* thrust; and (3) "*quiet*" thrust.

Aircraft with high-bypass-ratio engines (2 to 5 or more) are operated with only the *takeoff thrust* and *maximum climb* thrust, because the further reduction of thrust would yield only limited noise-abatement benefits.

"Standardized" Noise-Abatement Climb Procedures.

No single noise-abatement climb procedure meets the needs of all configurations of terrain and noise-sensitive areas relative to an airport, any more than a single flap setting and takeoff thrust can be standardized for all runway lengths, takeoff gross weights, wind conditions, and airport elevations.

Takeoff-climb procedures have differing effects on the noise immissions within the area covered by the initial climb to approximately 3,000 feet altitude above airport level (AGL); all have differing effects, generally overlooked, on the noise impact of the en route climb.

The following summary description is illustrated with sketches derived from Ref. 5.

1. The so-called "*original ATA/FAA procedure*" (1973), better known in Europe as the "*IATA method*," (see Fig. 2).^{*} The procedure initially consisted of a climb from liftoff to 3,000 feet altitude on takeoff power with takeoff-flap deflection; later, thrust was reduced from takeoff to maximum climb thrust at 1,500 feet, accompanied by a decrease in deck angle to

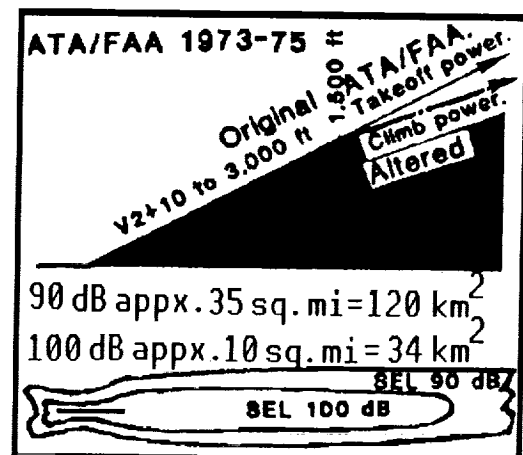


Fig. 2

^{*}Printed with permission of "The Air Line Pilot", Washington, DC.
(See ref. 6.)

maintain $V_2 + 10$ kt to 3,000 feet and subsequent airspeed acceleration and flap retraction.

2. The so-called "*NWA-ALPA procedure*," in Europe termed the "*modified ATA (or IATA) procedure*," in which the climb at $V_2 + 10$ kt on takeoff thrust is terminated at 1,500 feet, the deck angle is reduced from about 18° to 7° - 9° or a predetermined airspeed acceleration (0.5 to 1.5 kt/sec) or a specified rate of climb (500-1,500 fpm) is attained. The flaps are meanwhile retracted, and the engine thrust is reduced, until the "*quiet zero-flap airspeed, V_{ZF}* ," at the "*quiet EPR*" is attained, where V_{ZF} is the zero-flap maneuvering airspeed.

Exhaustive theoretical analyses and flight evaluations proved the effectiveness of the noise abatement afforded by that procedure over the original ATA/FAA procedure to up to 10 n.mi. from start of takeoff roll (Ref. 6).

3. The so-called "*AC 91-53 Procedure*," adopted in 1978 by the Federal Aviation Administration (FAA) and the Air Transport Association (ATA), incorporated the substance of the "*NWA-ALPA procedure*" with the altitude of the start of reduction of deck angle, flap retraction, and thrust reduction reduced from 1,500 feet to 1,000 feet, with a 300- to 500-

foot transition band (Refs. 5 and 7). The "AC 91-53" procedure has since been applied by air carriers with a variety of modifications.

4. The so-called "*Orange-County noise-abatement climb procedure*" in which, with high-lift devices in their takeoff position, thrust is reduced at 1,000 feet or less to afford maximum noise abatement to noise-sensitive areas close to the departure end of the takeoff runway, while the requirements of 14CFR25 (Ref. 8) for a minimum climb angle (appx. 1°) with one engine inoperative are satisfied. Similar procedures have been implemented at Washington National Airport, La Guardia New York Airport, and elsewhere.

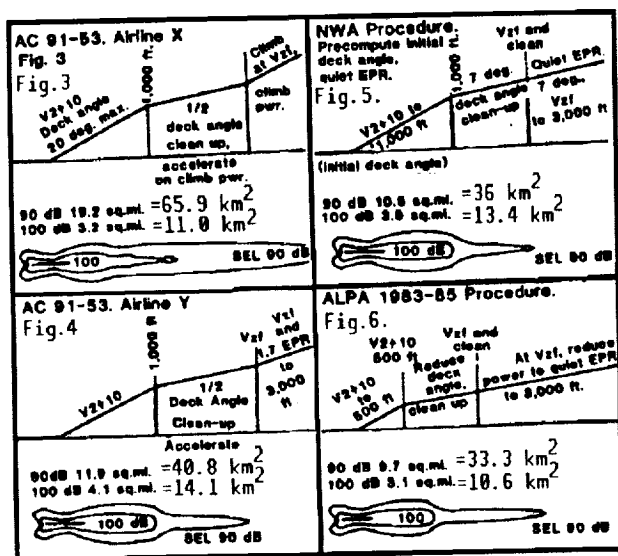
It has been the reported position of ALPA that thrust reduction, airspeed acceleration, and flap retraction in the interval between 400 feet and 1,000 feet altitude must be coordinated so that the FAR-25 minimum climb gradient in straight flight can be maintained with one engine inoperative and the remaining propulsive plant at its original EPR setting.

5. A "*New FAA Procedure*," deviating somewhat from the AC 91-53 procedure, first developed with cooperation from ALPA and others on Boeing 737 and MD-80 aircraft and later applied to heavier aircraft also. The procedure permits the following steps:

- (a) Takeoff EPR and thrust to at least 400 feet altitude.
- (b) Prescribed airspeed acceleration and flap retraction.
- (c) EPR reduction to "*quiet EPR*" at V_{ZF} (or at $V_{ZF} + 10$ kt, if flap retraction is still in progress).

Continued climb at $V_{ZF} + 10$ kt (or even at $V_{ZF} + 20$ kt, if the rate of climb and the deck angle increase at low gross weights.

Figs. 3 through 6 illustrate the noise immissions resulting from the application of the various noise-abatement climb procedures, as deter-



mined by ALPA (Ref. 5). All have different energy-loss implications on subsequent en-route noise.

A Note on Meteorological Influences.

The rate and angle of climb of an aircraft is increased by a headwind component and a vertical headwind gradient, decreased by a tailwind component and a vertical tailwind gradient.

Atmospheric sound absorption depends on air temperature, moisture content, the wind velocity and turbulence, and their vertical gradients, and the presence of substantial precipitation bodies within the airspace.

The global effects of the afore-described aircraft-performance factors was investigated by United Airlines in the early 1980s at the instance of the writer through a simulation of departures from the San Francisco Airport in conditions of a sharp subtropical temperature inversion at levels from 1,500 to 2,500 feet.

Noise immissions underneath the en route climb at 10 to 12 n.mi. from start of roll were increased or reduced by 3 to 8 dB by the use of various initial climb procedures..

A Note on the Sufficiency of Existing Scientific Knowledge.

It is submitted that current knowledge about the effectiveness of noise-abatement procedures and, more especially, the "downstream" effect of noise-abatement climb procedures in the airport environment on the noise immissions on the ground during the subsequent en route climb, is still insufficient.

Existing knowledge about the three-dimensional distribution of noise emission from actual aircraft in free flight should be improved. The accuracy of experimental verification of the application of scaling laws to the prediction of flyover jet noise with different climb procedures is still not universally conceded.

Dependable observational data on the noise emissions and performance capabilities of aircraft in realistic normal flight operation over variously shaped terrain appear indispensable for an understanding of the impact of en route climbing noise of aircraft over noise-sensitive areas with low ambient noise levels.

Trouble in the Department of En Route Climb Noise.

A lack of understanding of the sources and nature of en route climb noise has led to instances in which presumable noise-abatement procedures have created substantial increases in subsequent en route noise impact.

(1) Noise Abatement for Fish, Noise Overburdening of Humans.

During early 1987, a strange and previously unexpected increase in noise immissions in the City of Brisbane, California, situated on the eastern shore of the San Francisco Peninsula between the City of San Francisco and its Airport drew attention to the en route noise problem that can be caused by ill-conceived would-be noise-abatement climb procedures on takeoff.

As depicted in Fig. 7, the San Francisco International Airport has two pairs of dual takeoff and landing runways, namely, the shorter runways 01-19 and the longer runways 10-28. The prevailing wind comes from the west.

Takeoffs on Runways 01 proceed initially over the waters of San Francisco Bay. Departures from Runways 28 pass over century-old residential areas spread over terrain rising toward the San Bruno Gap (= Saddle) between Mount San Bruno and the coastal hills.

By 1957, virtually all departures took off from Runways 28. Severe complaints by the communities in the San Bruno Gap arose, and, pursuant to a proposal by the writer, the air carriers adopted a preferential runway procedure with most departures taking off from Runways 01 in

winds with westerly velocity components of up to 15 knots (later on, following another assessment by the writer in 1971, up to 20 knots).

In accordance with a revised "counterclockwise" Bay TRACON pattern of departure paths, developed and proposed by the writer between July 1968 and August 1969, southbound and southeastbound departures depart from Runway 01-Left, that is, facing north, make a 20° turn to the left as soon as practicable, then proceed over the waters of the Bay for approximately 4 n.mi., and initiate a left turn to cross the Peninsula. Virtually all of the climbs followed essentially the NWA-ALPA procedure and crossed the Brisbane at 4,000 feet altitude and airspeeds of 215 to 220 knots.

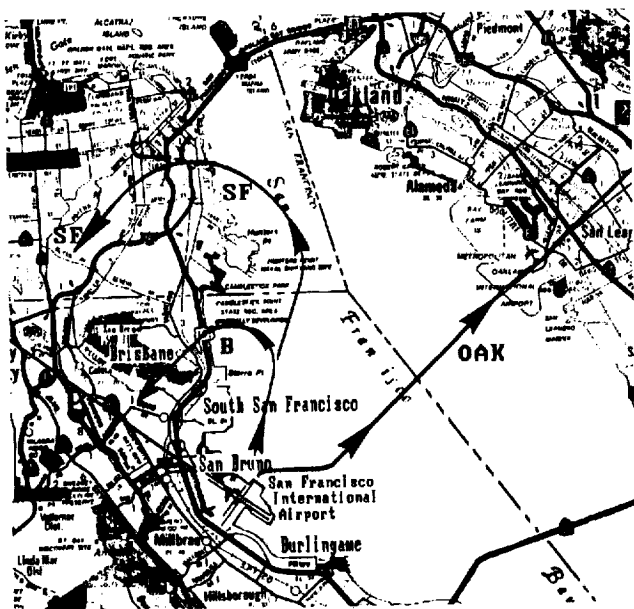


Fig.7. Departure paths from San Francisco International Airport, where noise-abatement climb procedures with deep thrust cutback can afford noise abatement to fish, but increase en route climb noise for humans.

For 18 years all was peace and tranquillity, until in the spring of 1987 one air carrier adopted an "Orange-County"-like departure procedure with a sharp cutback of thrust shortly after lift-off. With a climb gradient and airspeed accelera-

tion severely impaired, the aircraft followed the standard flight track and crossed into Brisbane at an observed altitude of approximately 2,700 feet and an airspeed of approximately 185 knots. Shortly thereafter, upon attaining an altitude of 3,000 feet almost directly above the residential hillslope area of Brisbane (point "B" in Fig. 7), the pilots, most of whom were not in accord with the entire "noise-abatement for the fish" procedure and concerned over their ability to meet a minimum-altitude restriction at the PORTE and PESCA Intersections along the coast, would increase EPR sharply to establish maximum climb power.

The result was easy to foresee, namely, a popular uprising by the people of Brisbane. Only the resolute intervention of the Airports Director and the Mayor of San Francisco dislodged the carrier from its insistence on its "new national noise-abatement procedure." Directly upon abandonment of the hapless procedure, the noise-complaint rate from citizens of Brisbane decreased from an average of 60 per day to an average of 2 per day.

(2) *In rising terrain, any thrust cutback may only intensify and extend the impact of en route climb noise.*

Underneath the climbpath originating from SFO Runways 28, the noise immission over the densely populated upslope terrain toward the San Bruno Gap depends on wind conditions.

In a strong westerly wind, the steep climbpath of departing aircraft minimizes the noise impact of the aircraft in any event.

When westerly or southwesterly winds are weak, departures from Runways 28 of the heaviest aircraft, for which Runways 01 are too short, create a serious noise problem.

So long as the climbout was generally performed according to the NWA-ALPA procedure, all went reasonably well. The "New FAA procedure," however, embodies not only an airspeed acceleration, but also a substantial

thrust cutback, even on aircraft with high-bypass ratio engines.

Now (Figs. 7 and 8) heavy aircraft remain closer to the rising terrain until, at 3,000 feet altitude, the restoration of full climb thrust results in an "outer noise island" of high single-event exposure levels in the en route climb comparable to those in immediate proximity to the Airport.

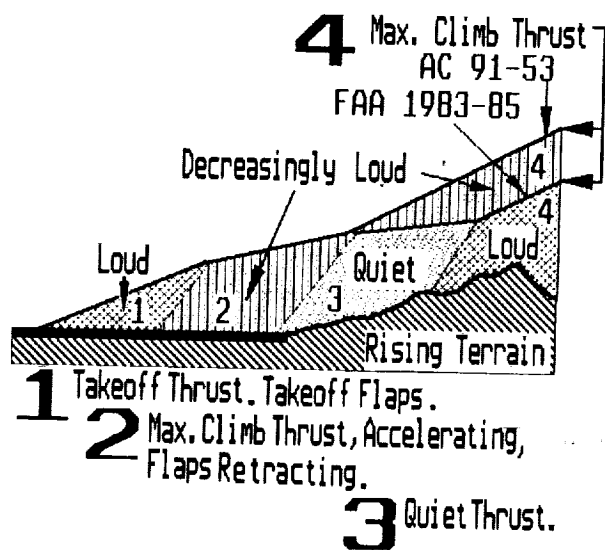


Fig. 8. Climb over Rising Terrain.

A combination of the Brisbane and San Bruno Gap situations obtains also over hilly residential areas of the City of San Francisco, which Runway-01 departures must overfly at a low above-ground altitude and low airspeed following the ill-conceived "noise-abatement climb" over the waters of the Bay.

Another comparable en route-climb situation is created by a persistence on the "noise-abatement climb" across the Bay of eastbound and northbound departures from SFO Runway 01R, which causes many aircraft to cross the eastern shoreline of the Bay and the residential areas along the slopes of the Oakland Hills at unnecessarily low altitudes.

No longer can most aircraft departing from San Francisco cross the OAK VOR at an altitude in excess of 4,000 feet as formerly. Hence, the procedure creates violations of the OAK

ARSA to the embarrassment of those concerned with flight safety and air traffic control.

To What Extent Can Noise-Abatement Climb Procedures Be Standardized?

Limits of standardization.

Standardization of cockpit procedures is mandatory in the interest of safety, but it, too, has a limit when a procedure is counterproductive. The writer has heard more than once from highly conservative pilots: "Don't they know we have some grey matter between our ears?"

Takeoff procedures are conducted pursuant to a standard takeoff plate, not according to a single configuration/EPR standard. Noise-abatement procedures, to the extent that they are essential, can also be conducted pursuant to a "takeoff-climb plate."

A noise-increasing procedure cannot be a standard noise-abatement procedure.

A so-called "noise-abatement procedure" which increases the noise impact either within the area covered by the takeoff climb or in adjacent en route climb areas significantly, should not be practiced with a disregard of local circumstances.

Optimal Standardization of Noise-Abatement Climb Procedures.

A proposal is made to (1) the national air-traffic control systems, (2) the International Air Transport Association (IATA), and (3) the International Air Line Pilots Association (IALPA) to adopt a pair of generalized "standard noise-abatement climb procedures" and, for a few airports impacted by noise-sensitive neighbors at the very end of a takeoff runway, a "desperation standard," all three of which should be available to pilots by means of clearly readable "climb plates" similar to existing takeoff and landing-approach plates.

The two generalized "standard noise-abatement climb procedures" should comprise:

- (1) the FAA/ATA AC 91-53 Procedure with its transition from takeoff EPR to maximum climb EPR at approximately 1,000 feet altitude, thereby reducing the en route climb noise for areas beyond about 6 n.mi. from start of roll
- (2) the "new FAA procedure," with its reduction to "quiet EPR" upon attainment of V_{ZF} and up to 3,000 feet, which affords noise abatement in areas between 3 and 6 n.mi from start of roll, but at a penalty in en route climb noise.

The "desperation standard," which involves a climb from minimum altitude to a specified thrust-restoration altitude with takeoff flaps and "quiet EPR" might be a last-resort procedure at a few exceptionally noise-impacted airports, but should under no circumstances be practiced systemwide, where at many airports the substantial loss in total energy of the aircraft is reflected in a heavy subsequent en route noise impact on areas at and beyond the climb-EPR restoration point. The "desperation standard" is not favored by pilots for obvious reasons of flight safety.

The foregoing proposal is made with due consideration of the effect of an initial noise-abatement takeoff climb on both the immediate environs of an airport and on more remote noise-sensitive areas subjected to the noise impact of an en route climb that is adversely affected by the curtailment of the total energy of the aircraft in the course of its initial takeoff climb.

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